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Comments on 'Scale Factors in Soil Science'

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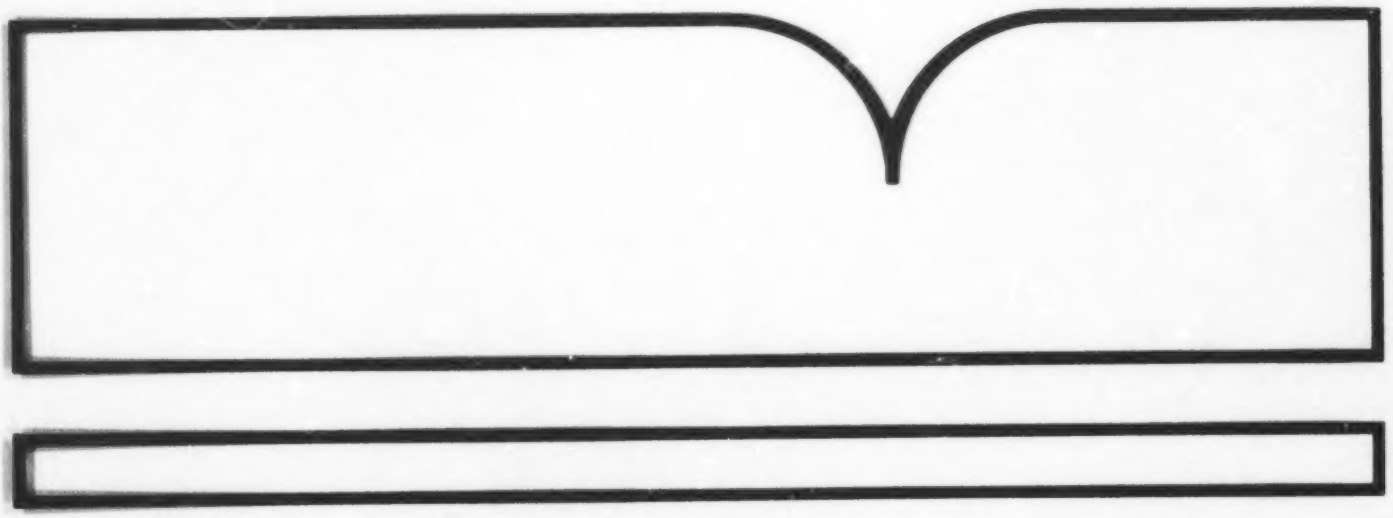

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JOURNAL ARTICLE

Comments on "Scale Factors in Soil Science"

Tillotson and Nielsen (1984) made a useful contribution by emphasizing that the method of "functional normalization" is unrelated to similarity principles, and scale factors obtained from the use of the method are not physically based. They illustrate a simplified version of the method by applying it to analysis of data on microbial CO_2 production in soils.

This comment will further emphasize the difference between functional normalization and similarity methods by presenting recent results reported by Shirazi et al. (1984). They used "inspectional analysis" together with actual analytical solution of system equations. They solved a nondimensionalized first order partial differential equation describing diffusion of CO_2 within a soil matrix of depth l with a uniformly distributed source term representing microbial CO_2 production.

The coupled CO_2 production-diffusion system was characterized by a diffusion rate constant η ($= D/l^2$) where D is diffusivity of CO_2 in soil matrix and by a biological production rate constant μ which is unknown but was back-

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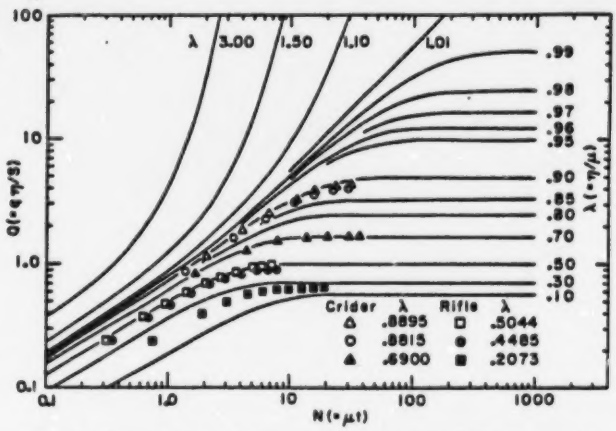

Fig. 1. Theoretical respiratory microcosm response Q expressed in generalized dimensionless coordinates. η is diffusion rate constant (d^{-1}), S is the slope of experimental CO_2-time curve at zero time mg g d^{-1}, t is time (d), and q is accumulated CO_2 (mg/g). From Shirazi et al. (1984).

calculated from the data using the nondimensionalized system solutions.

The family of solution curves in Fig. 1 is superimposed on typical data. The curves are expressed in nondimensional forms relating total production Q with incubation time N for various values of diffusion to production ratios of rate constants λ ($= \eta/\mu$). The dimensional production q is normalized by η/S where S is the slope of various experimental CO_2-time curves at $t = 0$. Its use here accounts for processing and inoculation of the soils before experimental incubation. A wide range of theoretical possibilities is defined by various values of λ. For example, at small values of λ, production is limited either by the deficiency of available carbon or by excessive resistance to diffusion, to mention only two possibilities. At large values of λ, theoretically there is little or no biological limit to production. The study of the solution curves would reveal many physically plausible explanations of the process dynamics.

The following discussion of the similarity aspect of the system is intended to sharpen the contrast with functional analysis approach.

The biological production of CO_2 is uniquely defined by N and λ for all experiments sharing the same initial and boundary conditions. These two dimensionless numbers are the necessary and sufficient defining parameters of all such experiments. Together with the requirement of shared initial and boundary conditions, N and λ group all "similar" experiments. The dimensionless production resulting from any experiment in the group does not depend on individual soil or biological characteristics separately. That is, not on diffusivity alone nor on a particular depth of soil, not the absolute value of diffusion time, nor the particular microbial population, but only on N and λ, however diverse might be the number of ways to obtain their two numerical values from other characteristics. For inifinitely large N and for $\lambda < 1$, Q becomes dependent on lambda alone. That is, $Q = \text{const}/(1 - \lambda)$.

Compare, for example, the results from Fig. 3 with Fig. 4 in Tillotson and Nielsen. Here, a family of four curves is collapsed into a single curve and all physical insight has been lost in the transformation. In the original untransformed system, K_m can be considered related to the time constant $1/\mu$, $1/\eta$, or both. For large values of time, m is related to λ as shown above. There is more information in Fig. 3 in the sense of similarity potentials than in Fig. 4.

Fig. 4 offers no utility for extension of data, for interpretation, or for better understanding of physical principles. The transformed curve is not invariant and would change with additional data. Thus, unlike the similarity approach which has a firmly established theoretical foundation and lends itself to efficient scaling, synthesis, interpretation and extension of experimental data, functional normalization which merely mimics the scaling aspect of similarity provides no comparable generalization. The comment provides a specific example to support Tillotson and Nielsen's discussion.

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Shirazi, M.A., B. Lighthart, and J. Gillett. 1984. A method for scaling biological response of soil microcosms. Ecol. Modeling 23:203–226.

Tillotson, P.M., and D.R. Nielsen. 1984. Scale factors in soil science. Soil Sci. Soc. Am. J. 48:953–959.

Reply to "Comments on Scale Factors in Soil Science"

We would like to thank Dr. Shirazi for further emphasizing the differences between scale factors derived from inspectional analysis and those derived from functional normalization. His comments regarding the CO_2 production-diffusion system clearly demonstrate that scale factors derived from inspectional analysis are composed of physical and biological characteristics of the system being studied while those derived from functional normalization are not. His discussion also reinforces the fact that inspectional analysis is useful because it reduces to a minimum the number of parameters required to completely define the system.

Shirazi et al. (1984) present an excellent example of the use of inspectional analysis in determining the biological response of soil systems. The example shows how inspectional analysis can be used to synthesize information contained in individual soil characteristics so that comparisons among responses for different soils can be accomplished in a more physically based framework. The example also shows the ability of inspectional analysis to predict actual biological responses if a few principal characteristics of the system are known. This is done by coupling inspectional analysis with the analytical solution of the governing nondimensionalized differential equations. We did not address this particular aspect of inspectional analysis in our publication; however, it is an important extension of the inspectional analysis procedure that should not be overlooked.

Although inspectional analysis results in physically defined scale factors, we do not wish to minimize the importance of those derived from functional normalization. Scale factors obtained through functional normalization are and have been helpful in elucidating the effects of spatially heterogeneous soil properties on processes which occur at the field scale.

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